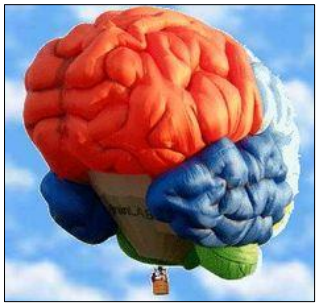
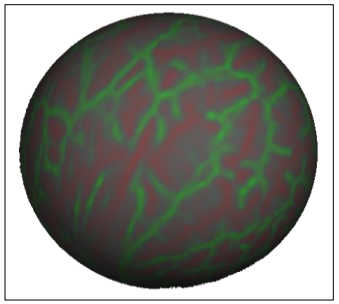
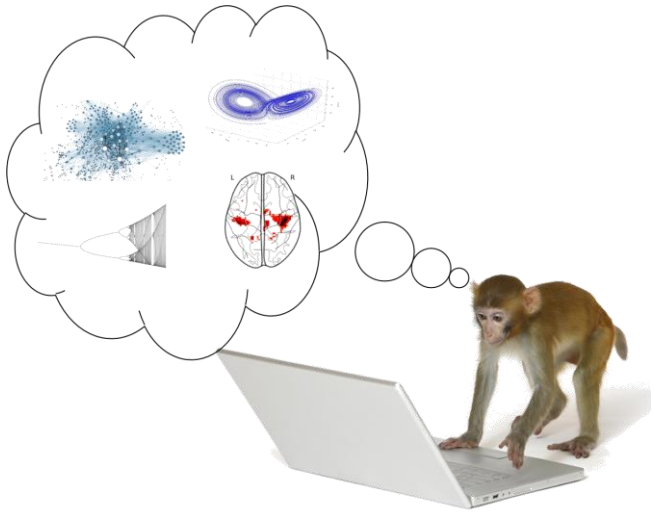
Introduction to Neuroimaging

for Algebraic Topologists







Dr. John D. Griffiths

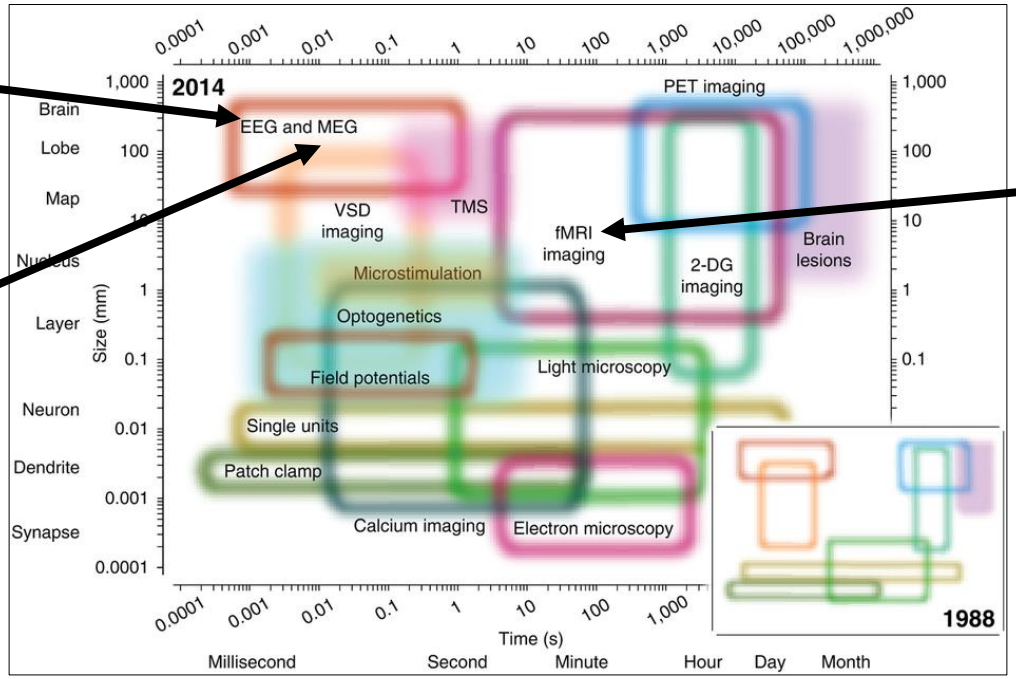
Rotman Research Institute

Baycrest, Toronto

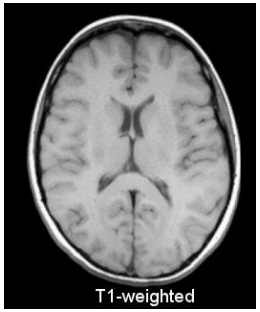
Overview

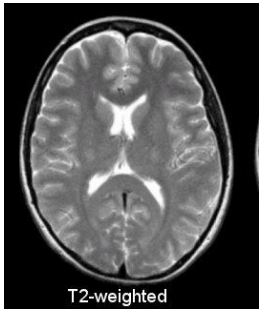
- Structural MRI
  - Modalities & Contrasts
  - Macro-neuroanatomy
  - Registration
  - Parcellations
  - DWI Tractography
- fMRI
  - Origins of the BOLD signal
  - Experimental Paradigms
- M/EEG
  - Origins of the M/EEG signal
  - Source localization
- Connectivity
  - The three Cs
  - Connectomics
  - Neural mass modelling

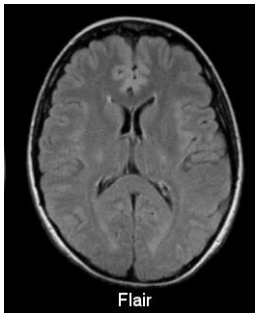
Tools of the trade



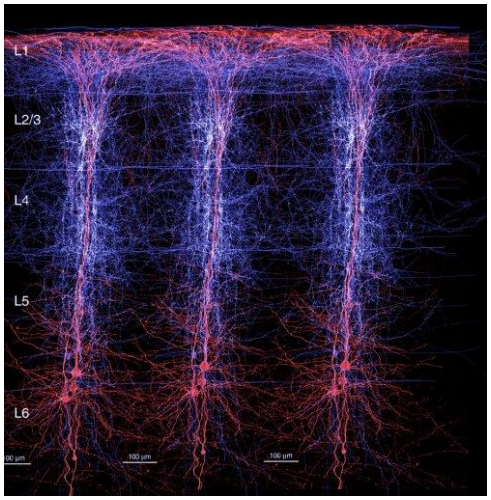
Imaging Brain Structure

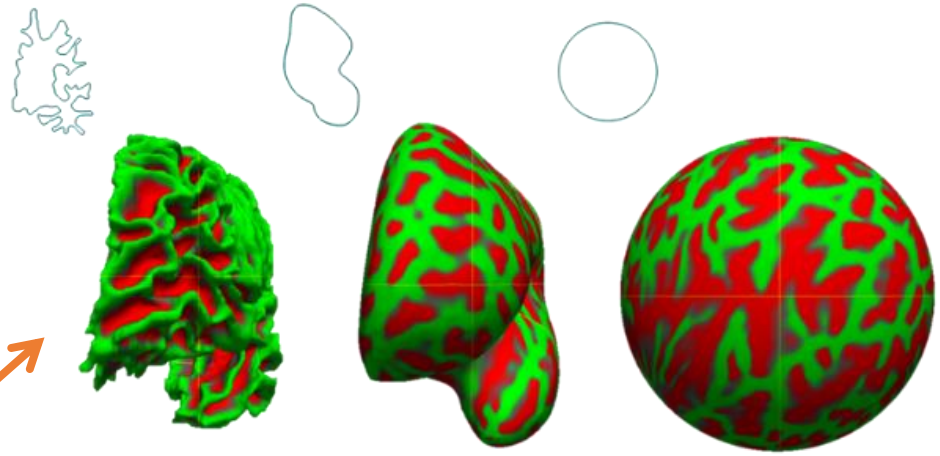


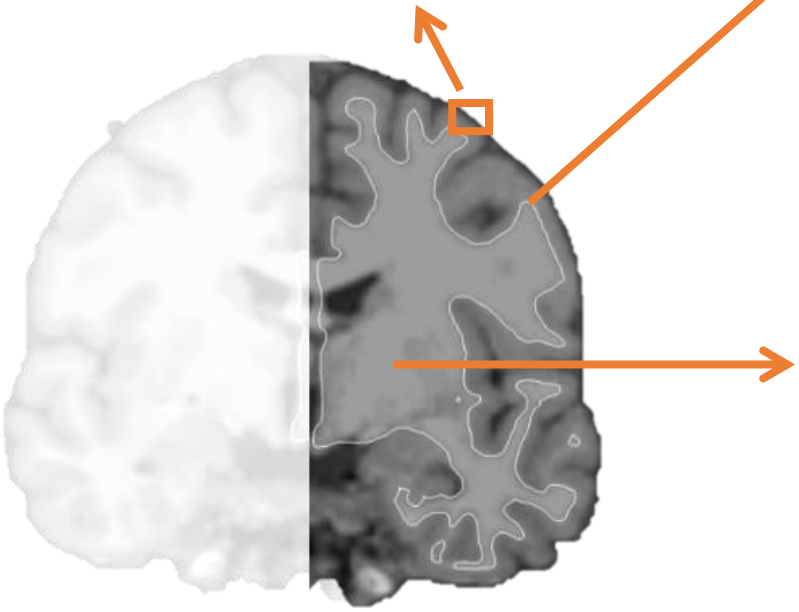


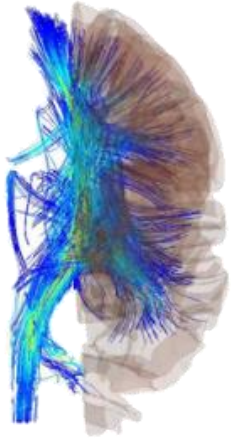


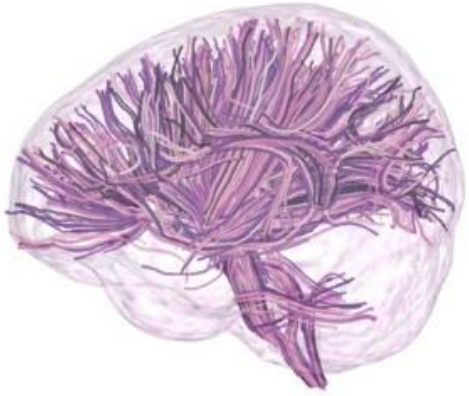
Macroscopic Cortical Anatomy



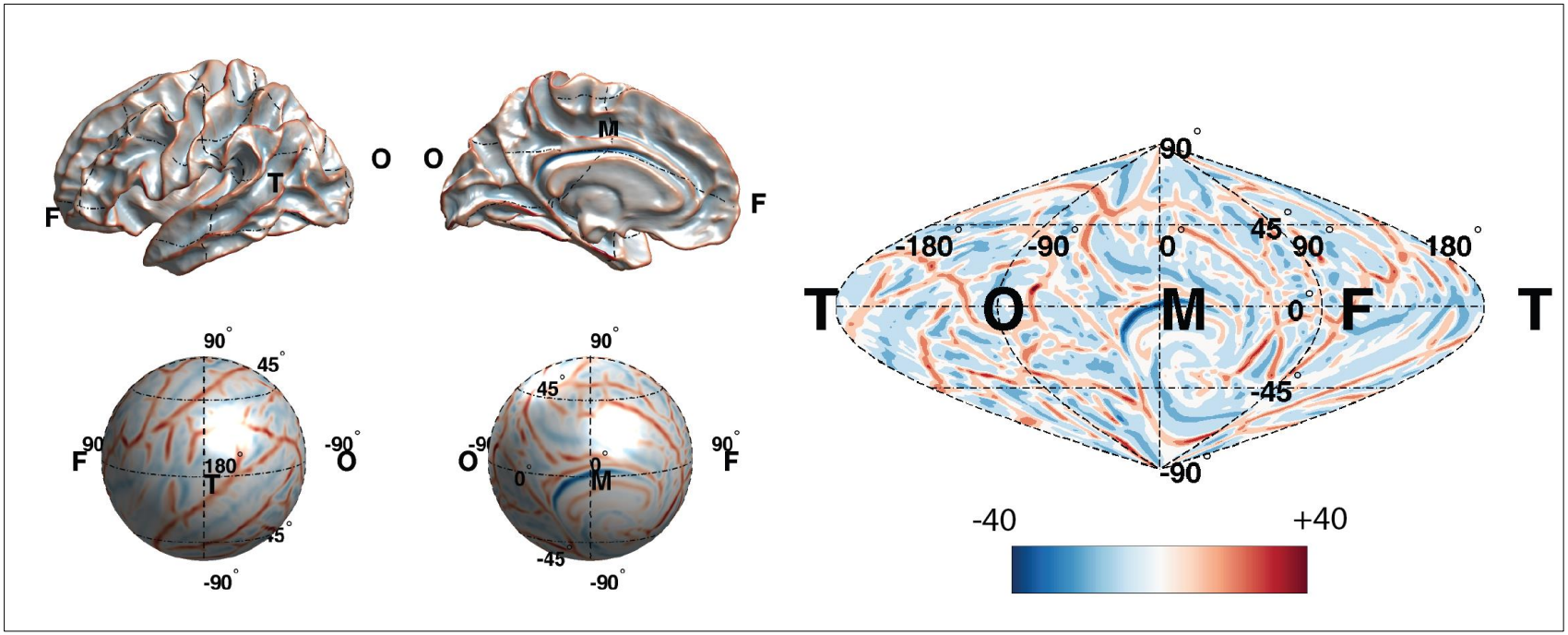








Spherical topology of cerebral hemispheres



Robinson et al. 2016

(see also: http://gallantlab.org/brainviewer/sulcigyri/)

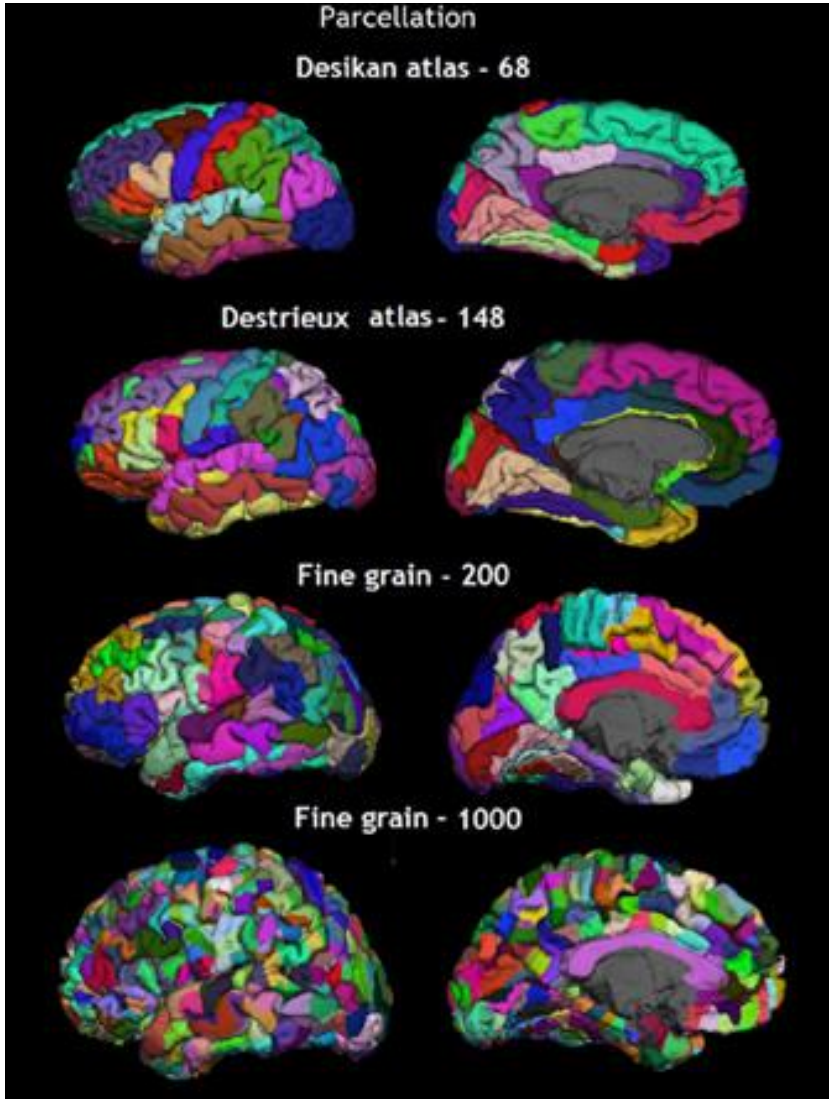
Parcellations

Can be thought of as neuroanatomically principled form of data downsampling

Quite a few around…

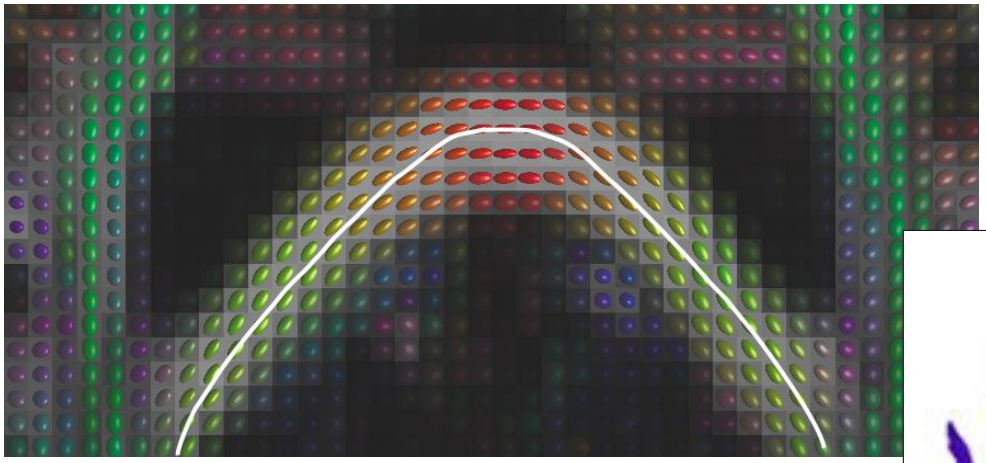
Bit of a wild west…

Rapidly evolving field



Krishnadas et al. 2013

Tractography



Origin of the BOLD signal

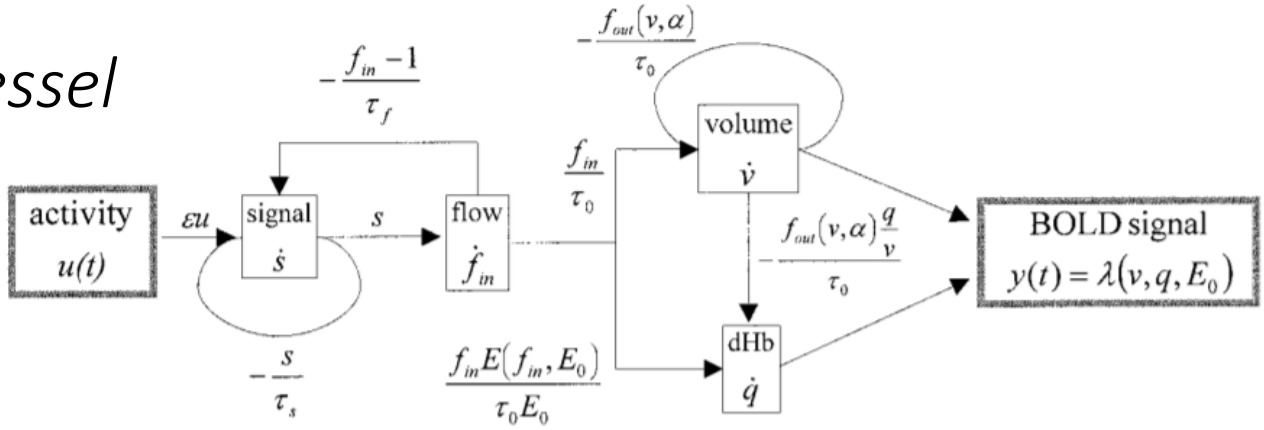
Blood oxygenation-level-dependent (BOLD) signal:

Neural activity -> increased oxygen consumption

-> increased blood flow

-> change in magnetic susceptibility

'Balloon-Windksessel Model':



Friston et al. 2000

Experimental & Statistical Paradigms

'Classical' mass-univariate analysis

HRF-convolved boxcar regressor

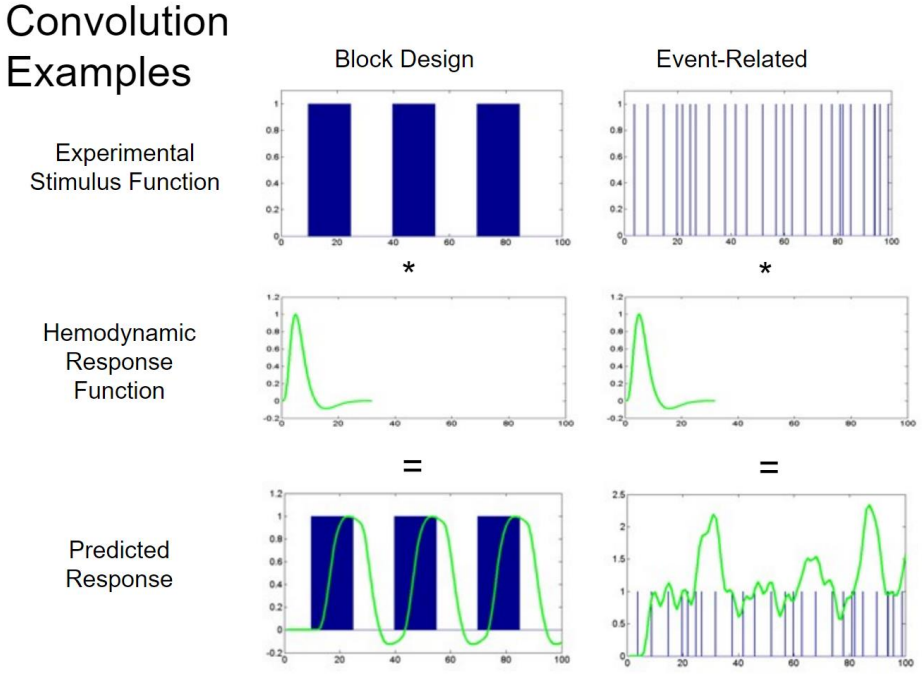
-> beta -statistic images for each contrast

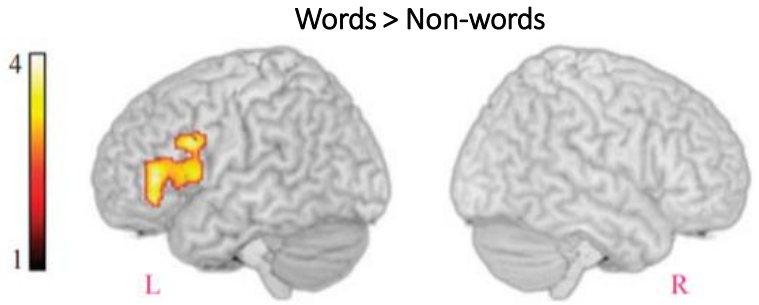
first-level mass-univariate analysis

-> t/F statistic images for each subject

Enter into second-level (group) analysis

-> 'activation maps'





Marslen-Wilson & Tyler, 2007

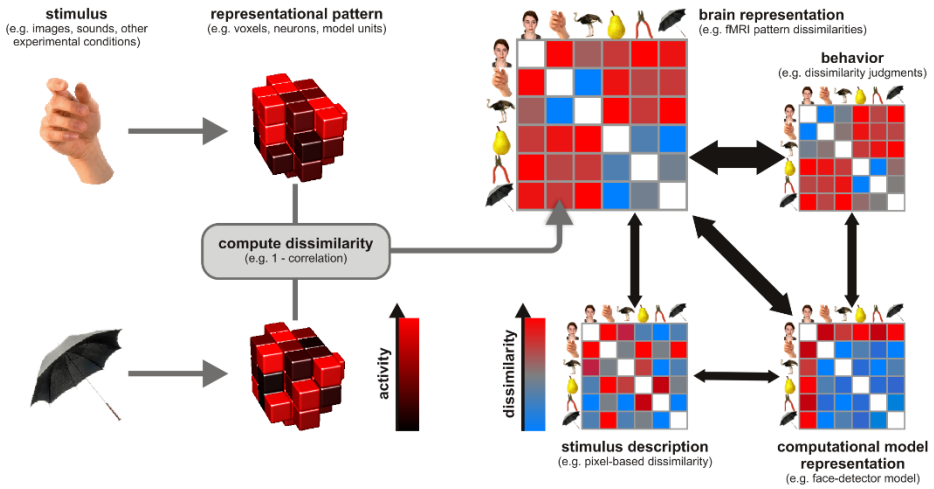
Experimental & Statistical Paradigms

Multi-voxel pattern analysis

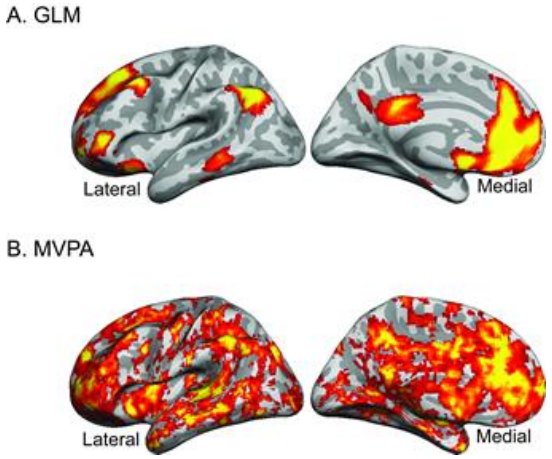
HRF-convolved boxcar regressor

-> beta + t/F -statistic images for each contrast, for each subject

multivariate analysis on patches of voxels



Kievit & Kiregeskorte 2013



Experimental & Statistical Paradigms

Resting State

What?

1. An experimental paradigm (barely) for measuring brain activity at rest
2. What the brain is doing at rest
3. Specific, canonical patterns of coherent low-frequency fluctuations. At rest.

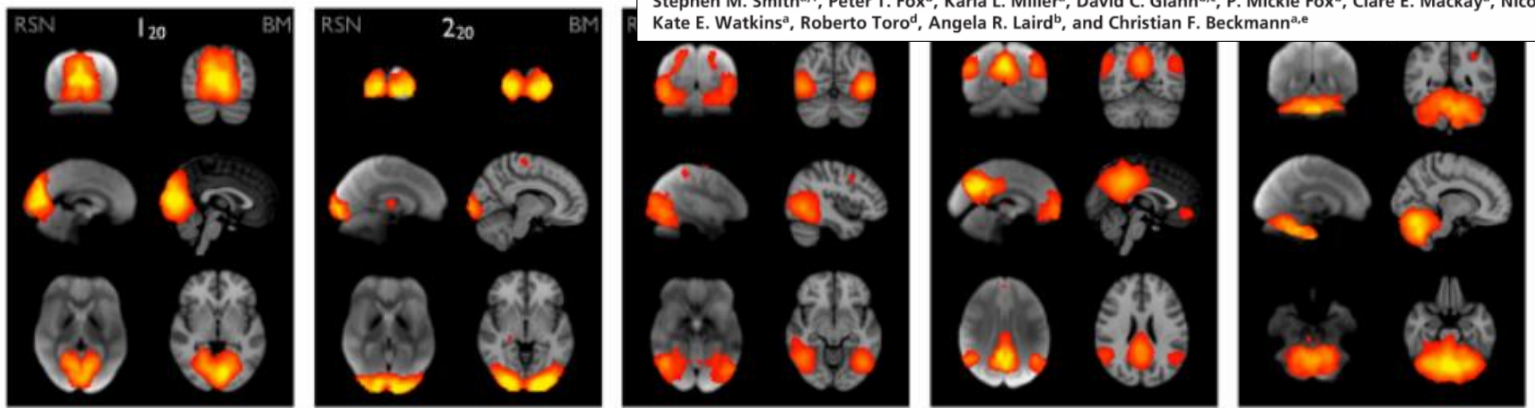
   -> 'RSNs'

Why?

- Flexible, easy, practical…etc..
- *Links to neurocognitive structures*

Correspondence of the brain's functional architecture during activation and rest

Stephen M. Smith[a,1], Peter T. Fox[b], Karla L. Miller[a], David C. Glahn[b,c], P. Mickle Fox[b], Clare E. Mackay[a], Nicola Filippini[a], Kate E. Watkins[a], Roberto Toro[d], Angela R. Laird[b], and Christian F. Beckmann[a,e]



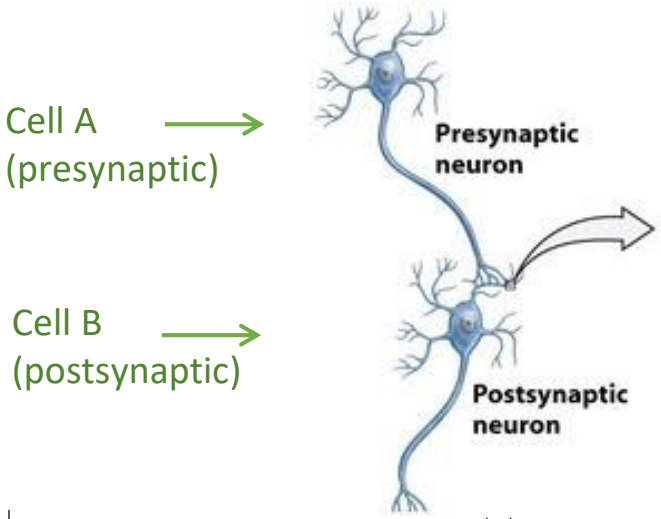
Smith et al. 2009

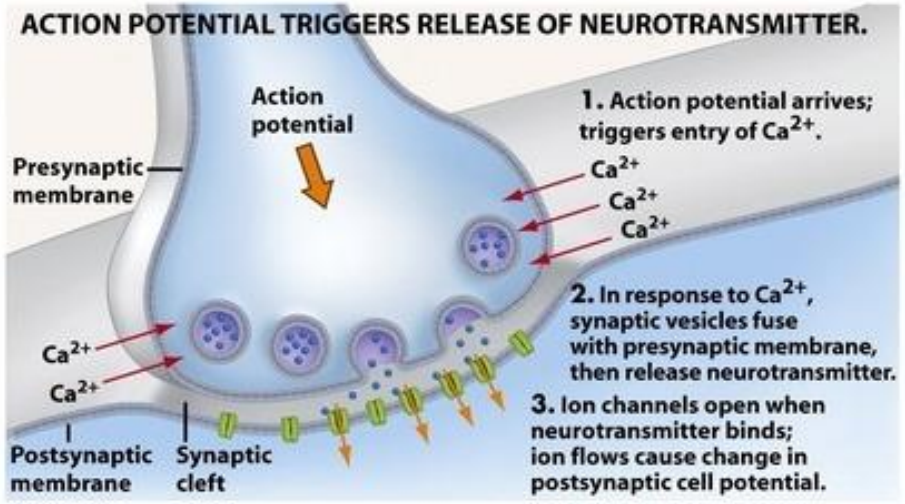
Baycrest
Rotman Research Institute

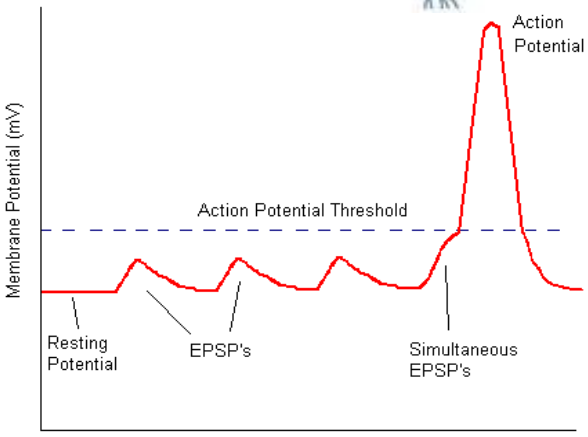
Qs?

Physiological Basis of M/EEG signals

1. Action Potentials and post-synaptic potentials



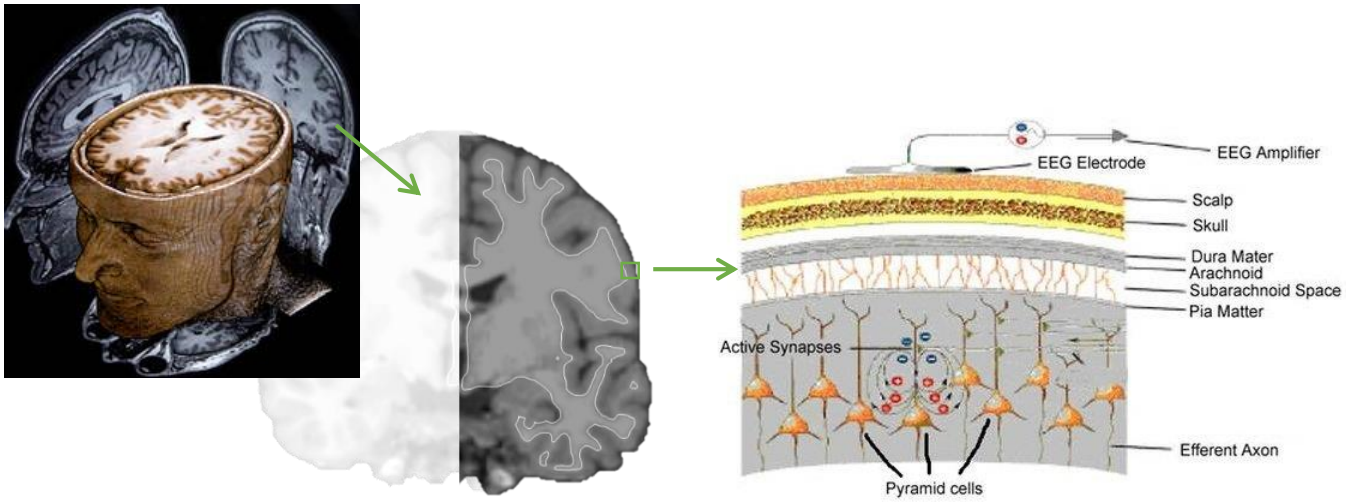




- Cell A fires
- Action potential travels along axon of cell A
- Cell A releases neurotransmitter (generally)
- EPSP / IPSP at dendritic / somatic membrane of cell B
  = micro-current source & origin of EEG signal

Physiological Basis of M/EEG signals

2. Apical dendrites in the cortical ribbon



Synchronized micro-current sources due to PSPs in aligned apical dendrites of cortical pyramidal cells summate to produce **meso-current sources**

Physiological Basis of M/EEG signals

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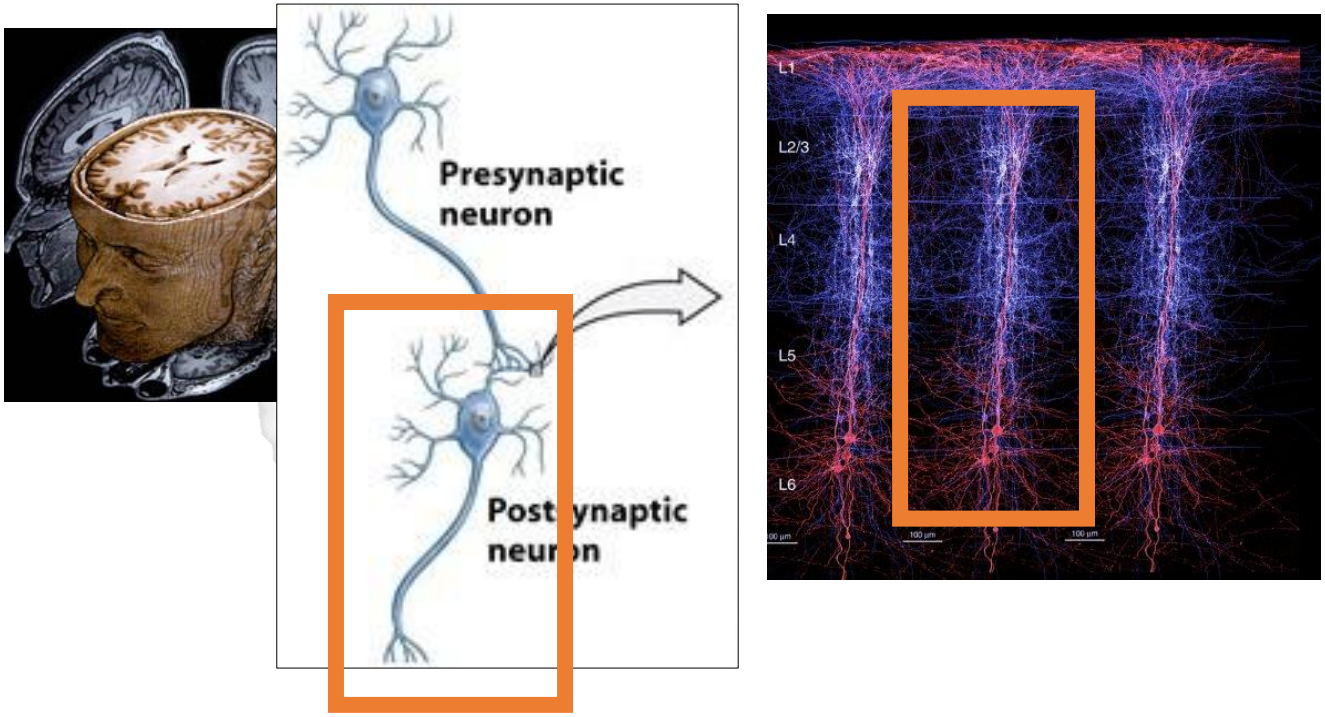

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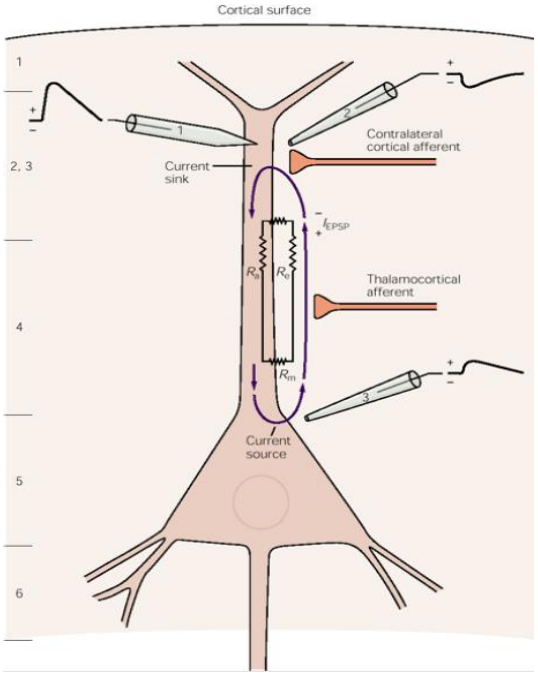
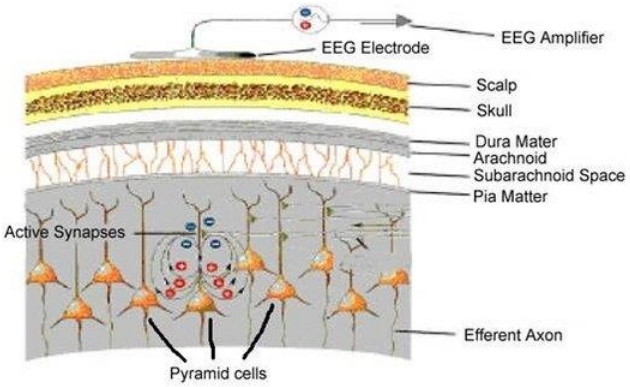
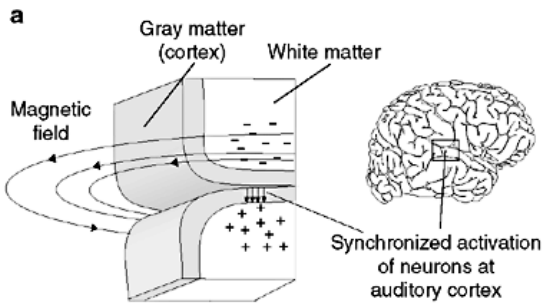
Physiological Basis of M/EEG signals

3. Micro- and meso-current sources

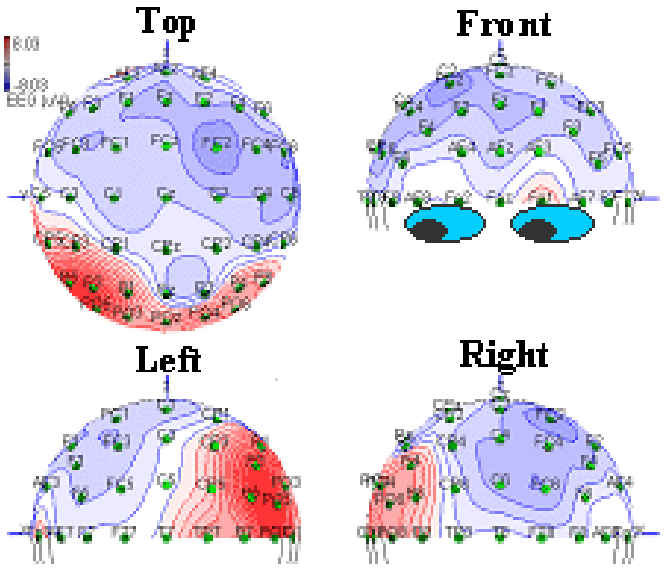


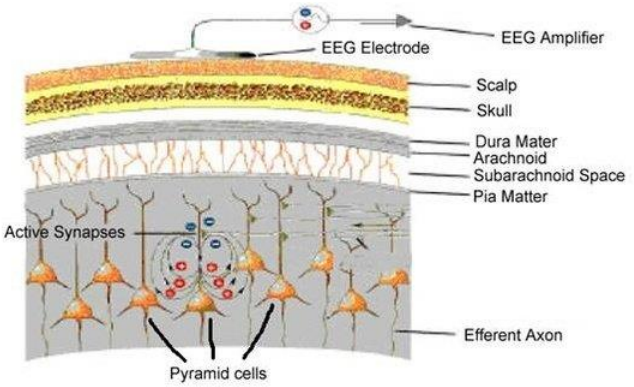


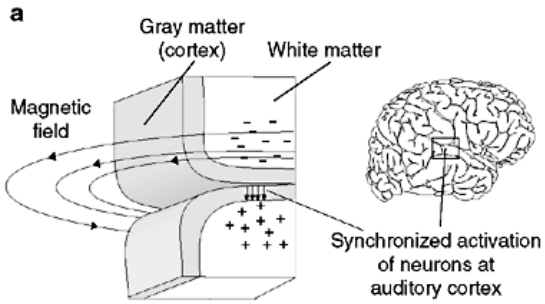


Physiological Basis of M/EEG signals

4. Electrical/magnetic field distribution on the scalp







Physiological Basis of M/EEG signals

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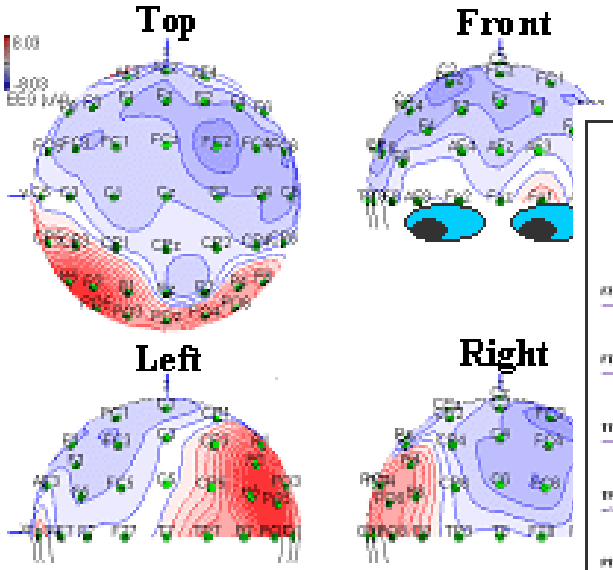
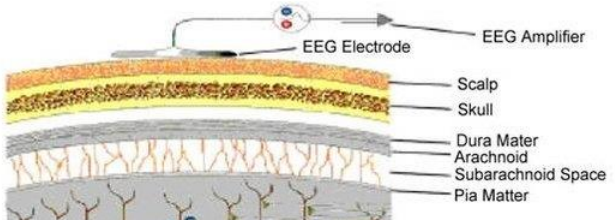
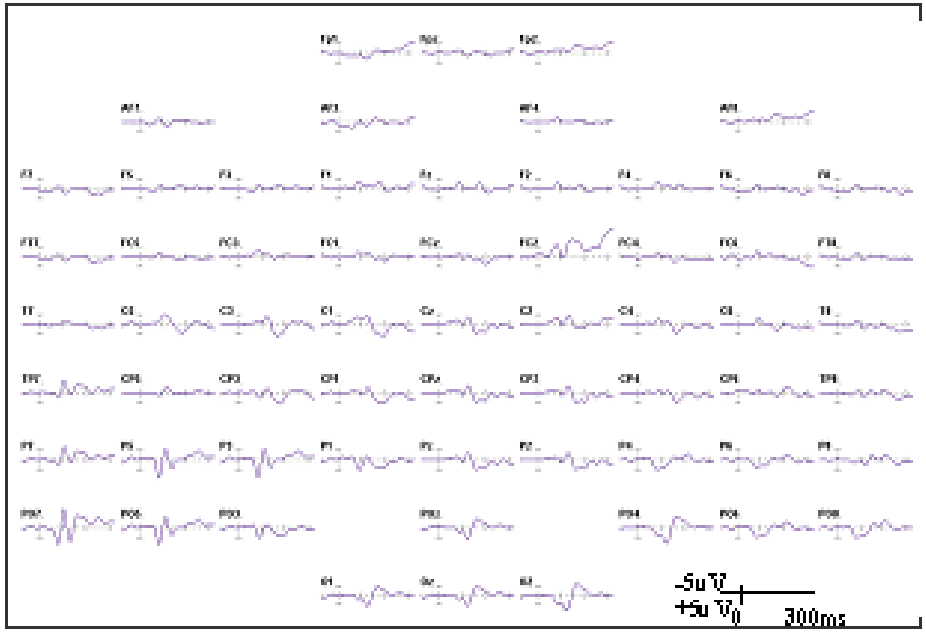
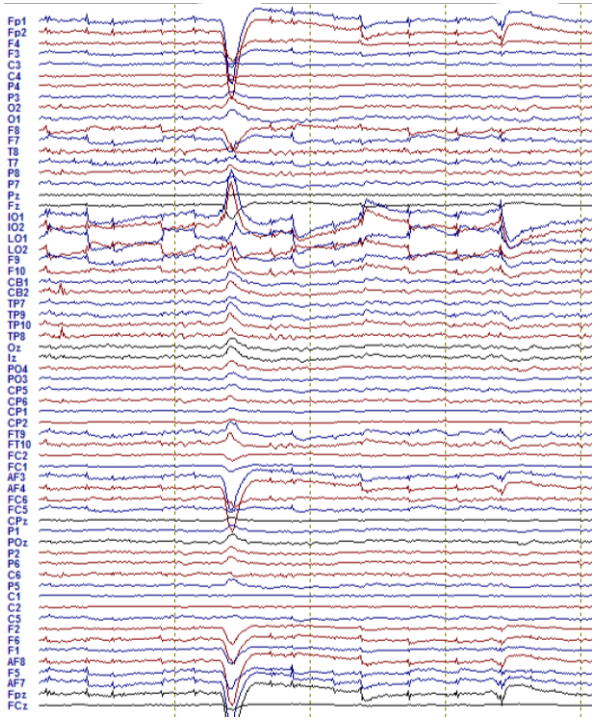
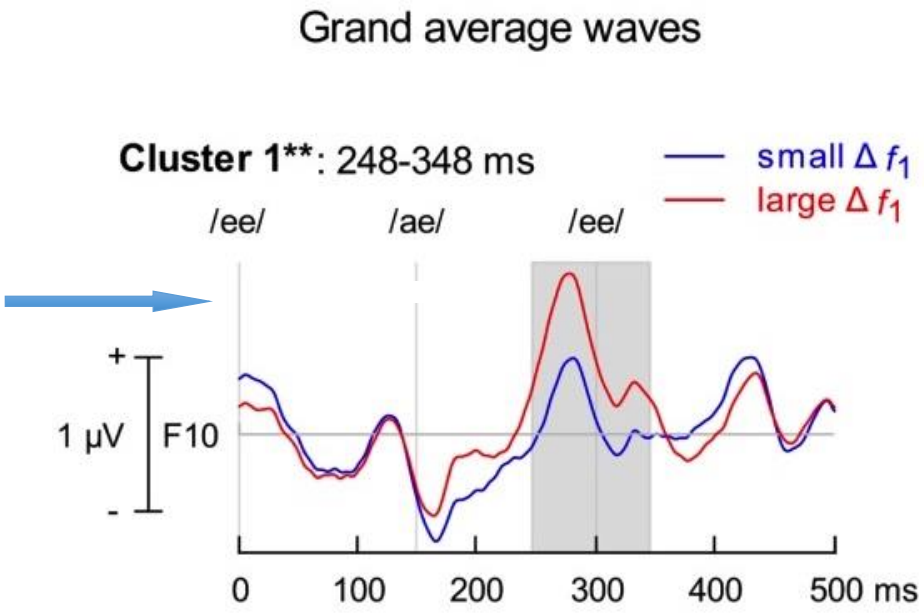






Event-related potentials (ERPs)





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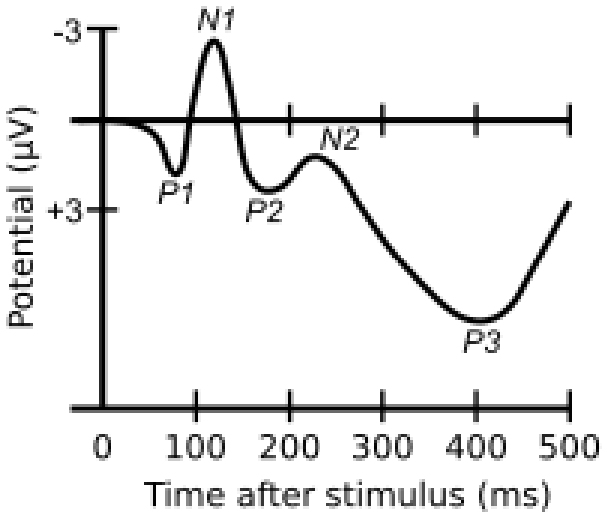
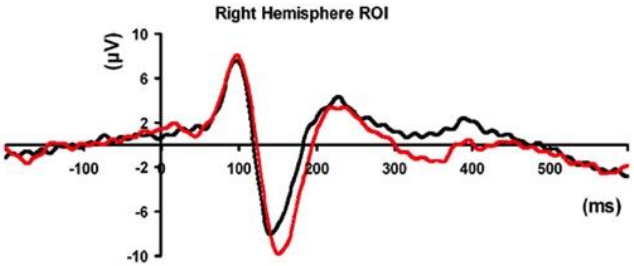
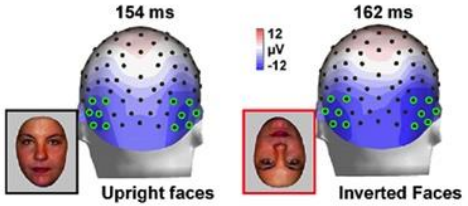






Main components:
N1, P2, MMN, N2b, N2pc, P300 (P3a, P3b), N400, P600

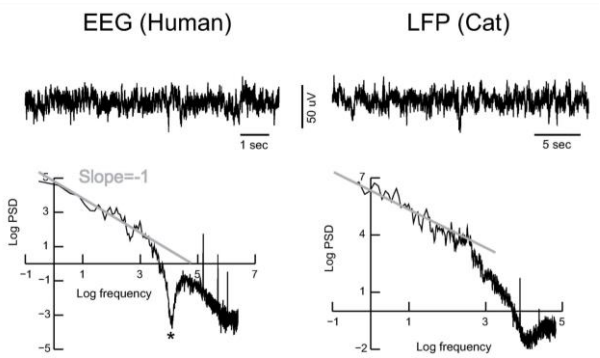
Main classification:
exogenous/endogeneous

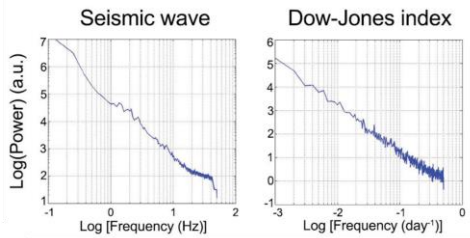
Component magnitudes + latencies are modulated by cognitive manipulations

Frequency & time-frequency analysis

Power law scaling

- log power is a linear function of log frequency with some exponent α

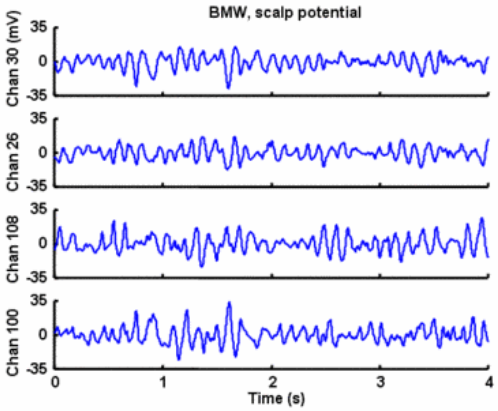


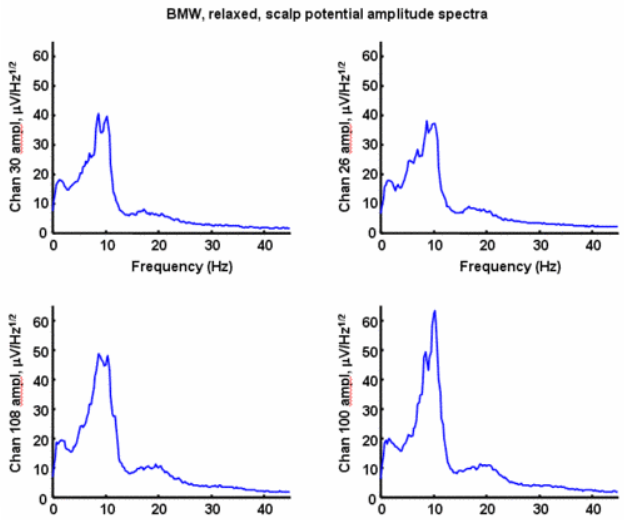


Bedard et al. 2016; He et al. 2010

Alpha rhythm

- (by far) most dominan spectral feature of EEG
- Slows with age
- Multiple spatial components





Nunez et al. 2006

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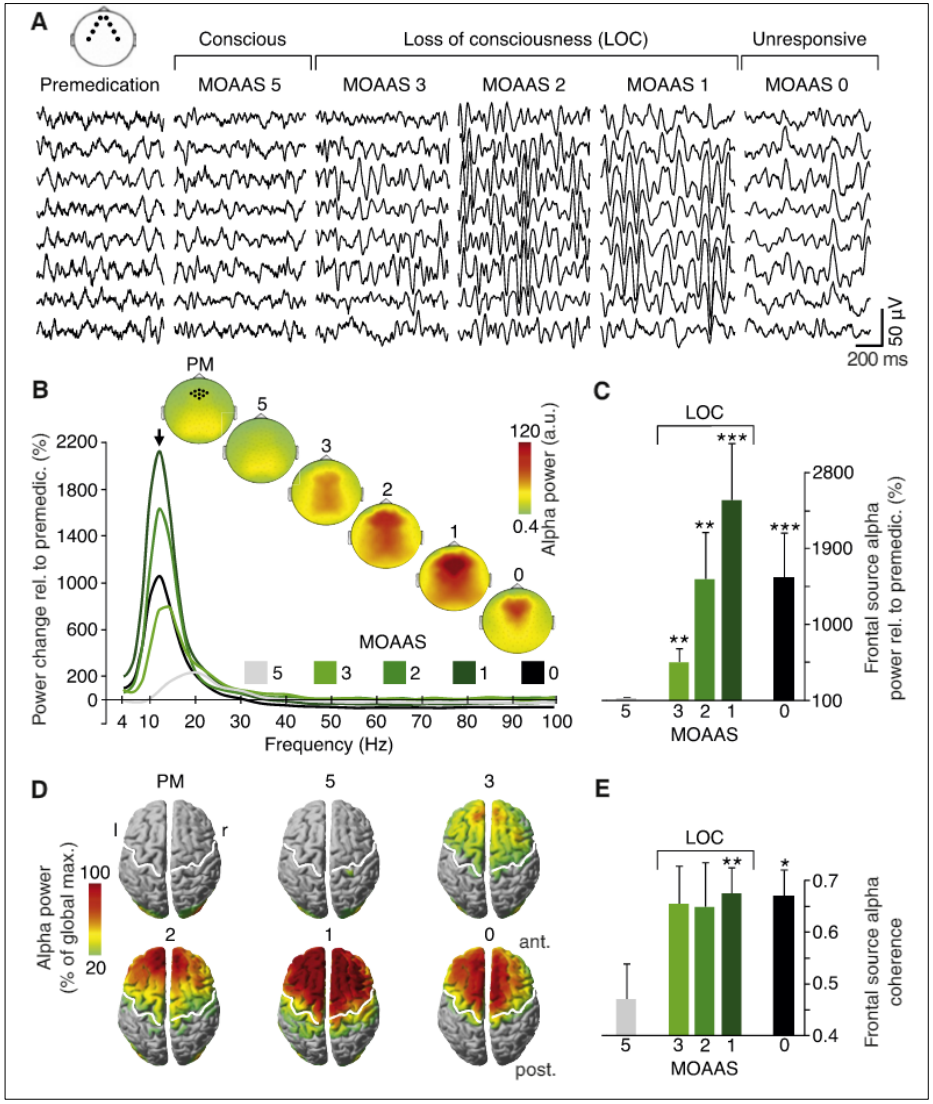


Supp et al. 2011

Multi-scale entropy

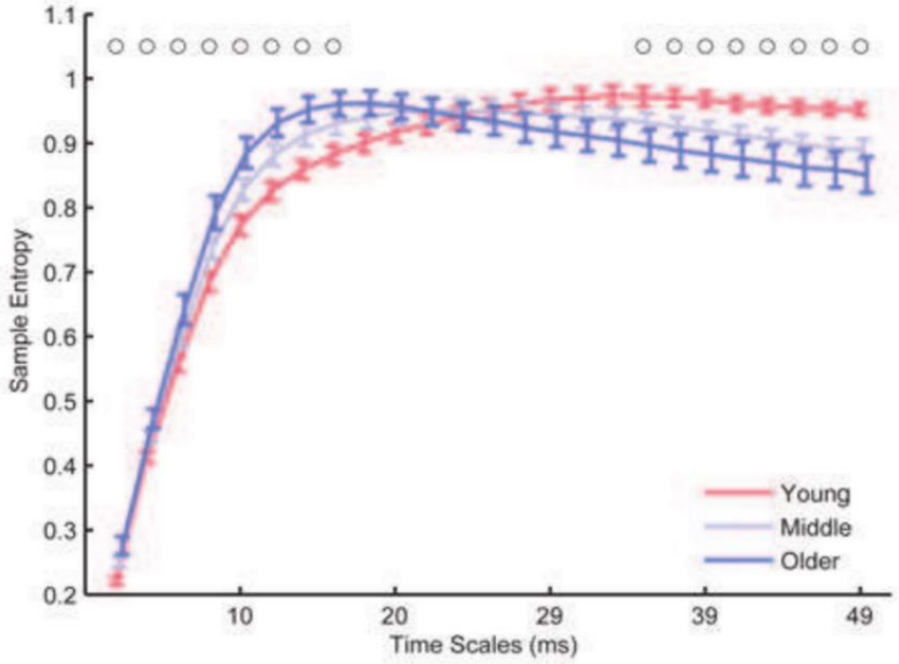
Sample entropy:

"Negative logarithm of the probability that if two sets of simultaneous data points of length m have distance <r then two sets of simultaneous data points of length m+1 also have distance <r"

SE = -log (A/B)

where
A = # of length m+1 pairs with difference < r
B = # of length m pairs with difference < r

Measure of *regularity* or *complexity*



McIntosh et al. 2013

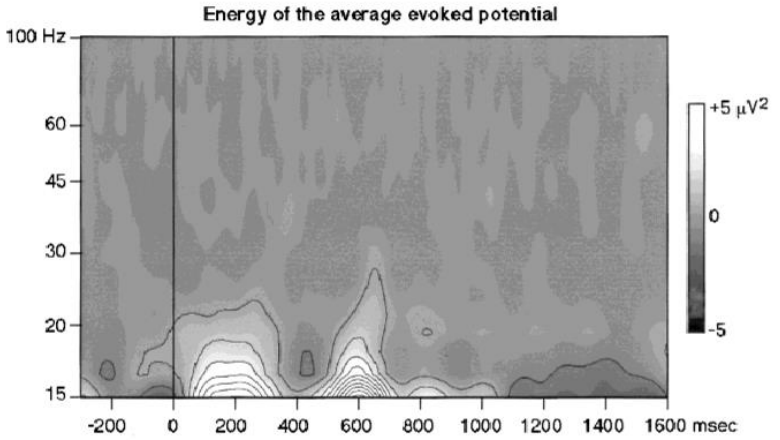
Multiscale entropy:

sample entropy for multiple levels of downsampling

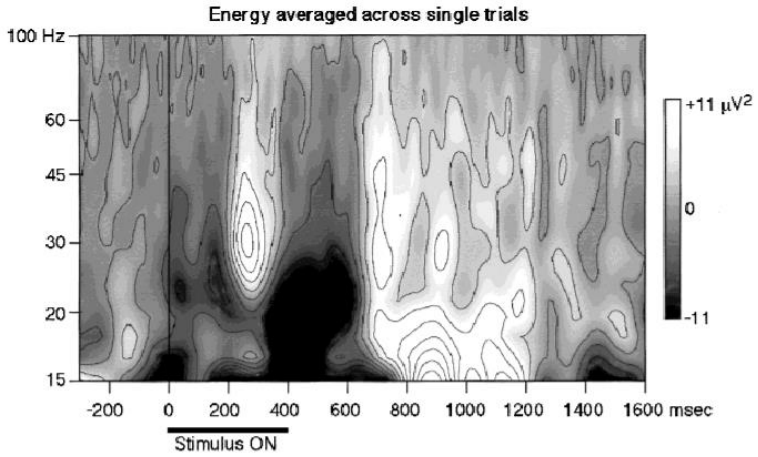
changes with age, development, cognitive state

Evoked vs. Induced Responses

Evoked power:
average > TF decomposition



Induced power:
TF decomposition > average



Tallon-Baudry et al. 1999

M/EEG Source Analysis

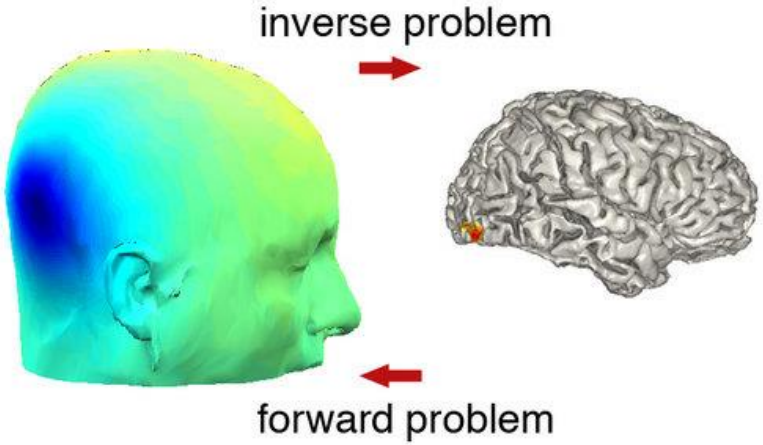
Problems and strategies

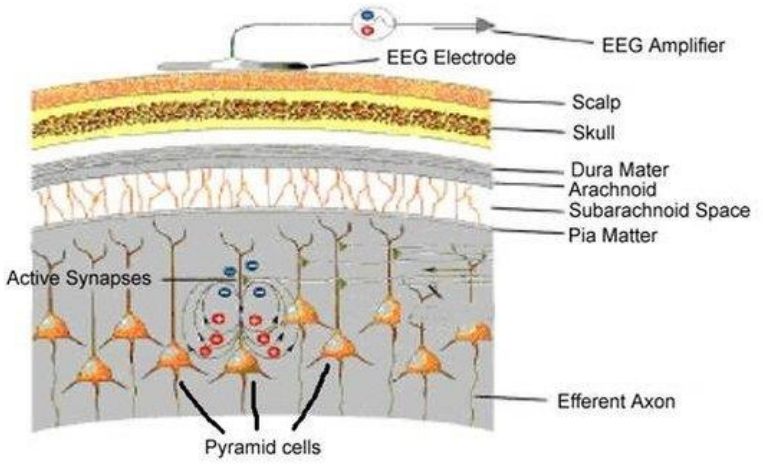
Inverse problem is ill-posed; requires constraints

Three families of approaches:
- Focal dipole modeling
- 'Scanning' / spatial filters
- Distributed source modelling

Main source of error: registration

EEG data requires more detailed tissue conductivity models than MEG





M/EEG Source Analysis

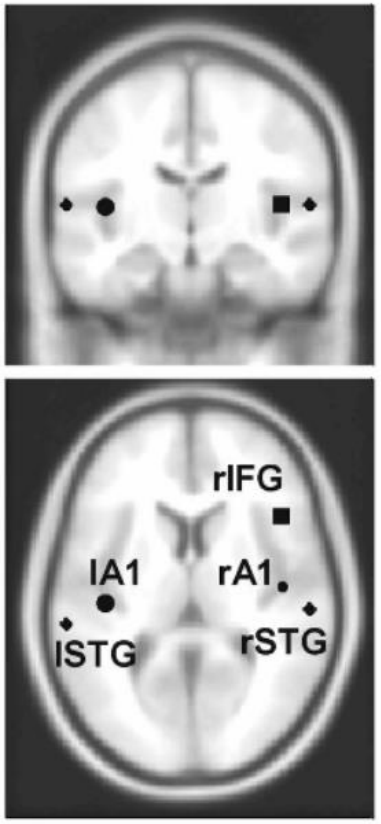
Dipole Modelling

5 parameters (per dipole):
- position (x,y,z)
- orientation (theta,phi)

Incrementally add in until best fit / most parsimonious fit

Not always 100% automated (v. nonlinear optimization problem)

Not recommended….



Garrido et al. 2007; 2009

M/EEG Source Analysis

Beamforming

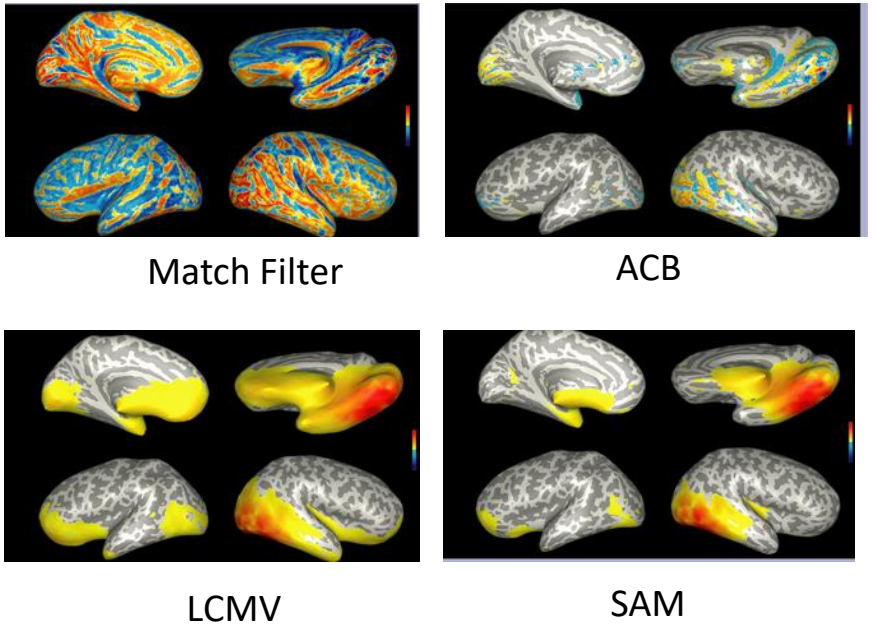
spatial filter, optimized independently for every source location

not an inverse solution

SAM: scalar, nonlinear; find dipole orientations that maximize total power/noise ratio

LCMV: vector, linear; maximize variance subject to unity gain constraint

(not generally used in EEG…)



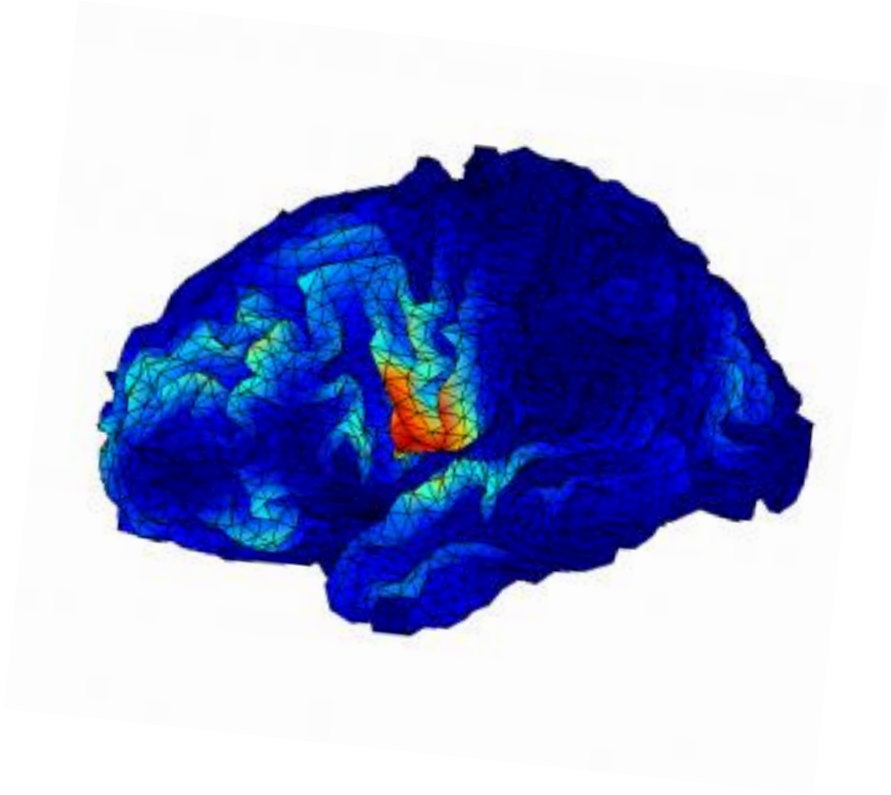
Ramirez 2008

M/EEG Source Analysis

Distributed Inverse Source Models

Assumed fixed dipole orientations from cortical surface

-> linear, undertermined system of eqs **B** = **L**J + **E**

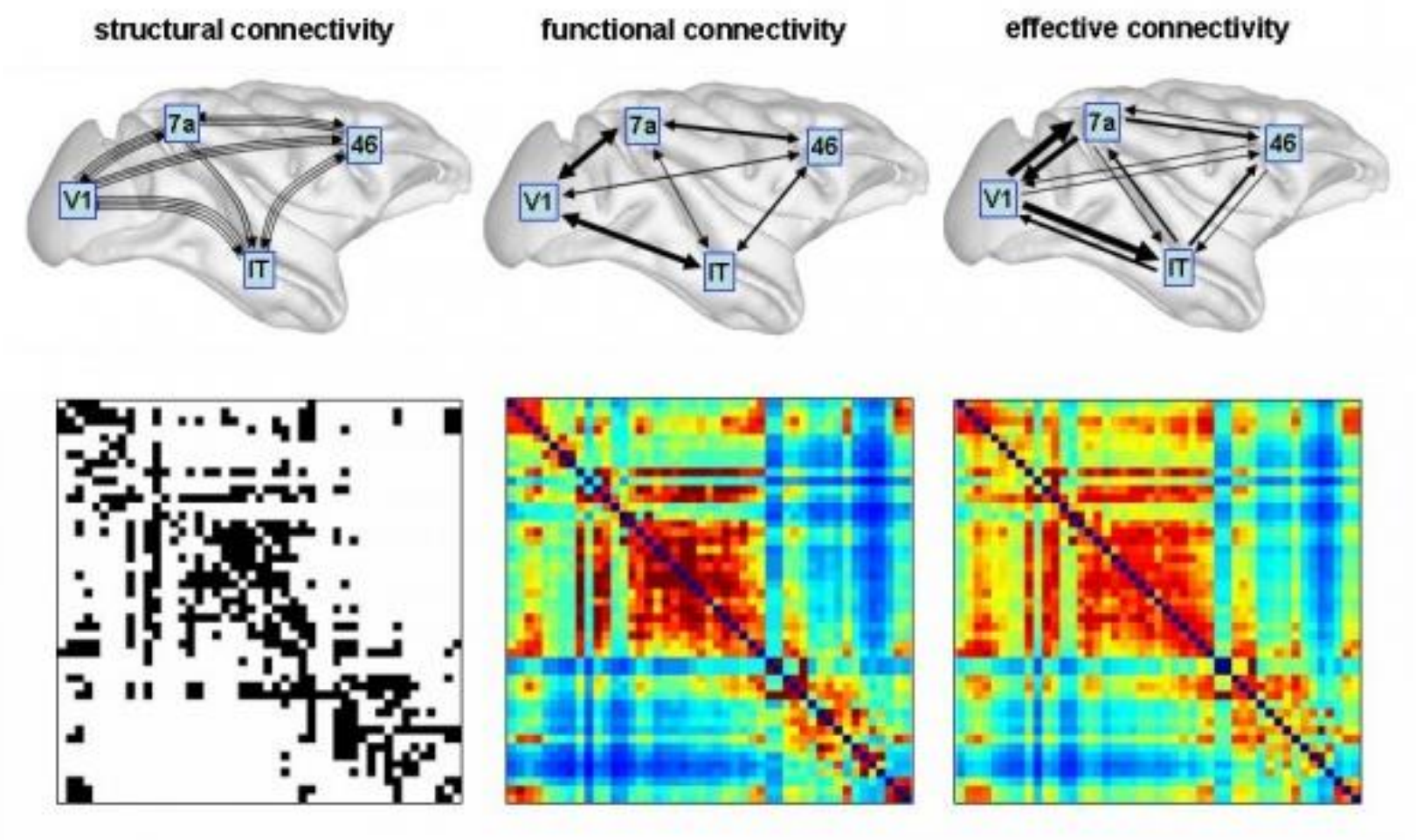


Algorithms differ in regularization, depth-weighting, priors on source locations, sparsity

Baycrest
Rotman Research Institute

Connectivity & Networks

The three C's



Sporns 2007

Functional/Effective Connectivity

Metrics of choice

fMRI

- Pearson Correlation
- Partial Correlation
- Wavelet coherence
- ICA

M/EEG

- Imaginary Coherence
- Phase synchrony
- Bi/Multivariate Time/Freq domain Granger Causality
- Band-limited power correlations

Connectomics

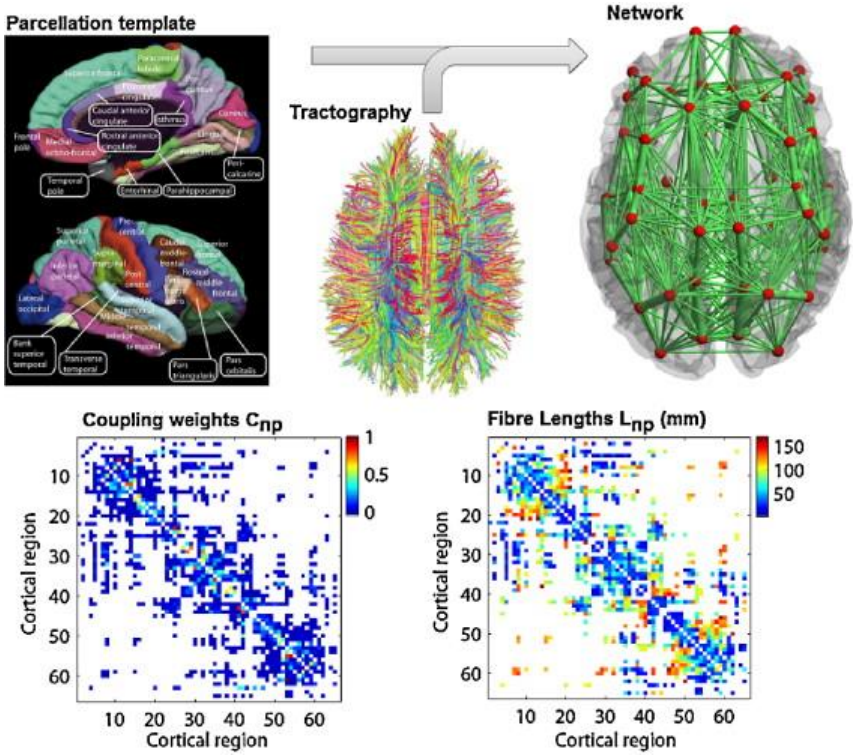
Connectome

From Wikipedia, the free encyclopedia

A **connectome** (/kəˈnɛktoʊm/) is a comprehensive map of neural connections in the brain, and may be thought of as its "wiring diagram". More broadly, a connectome would include the mapping of all neural connections within an organism's nervous system.

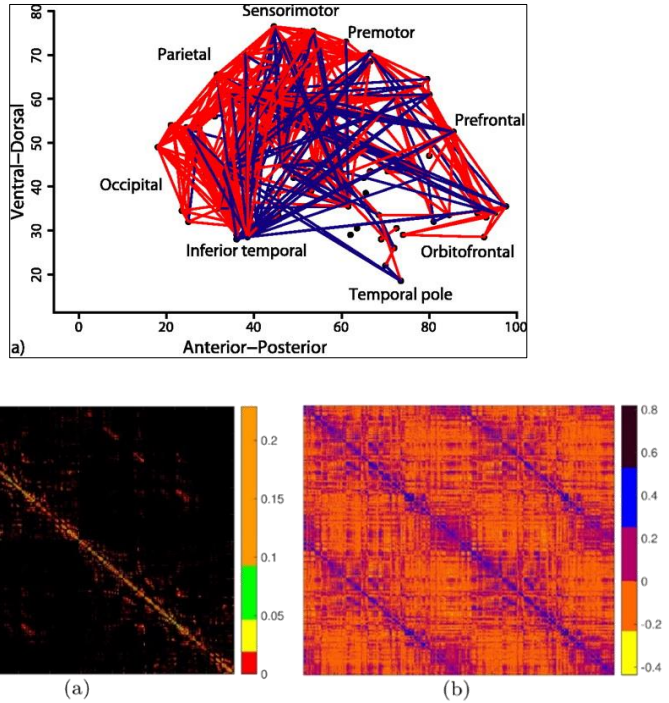
Connectomics

Structural connectome



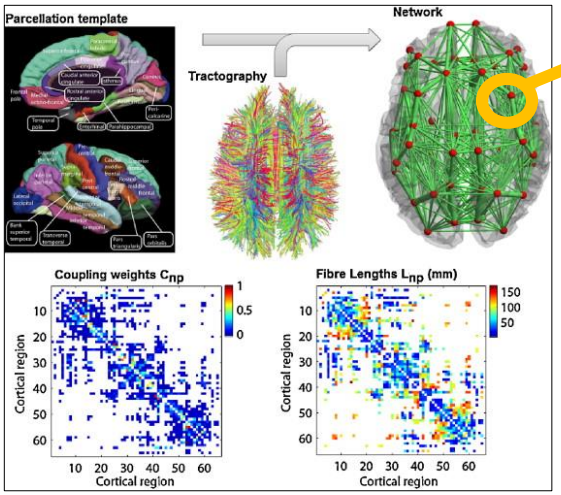
Daducci et al. 2012

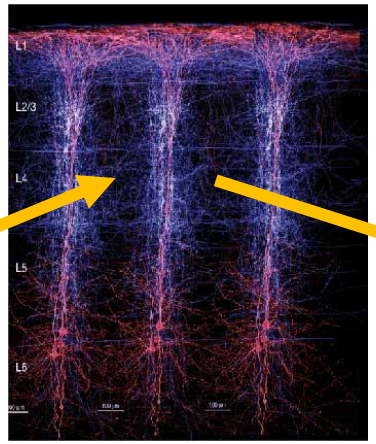
Functional connectome

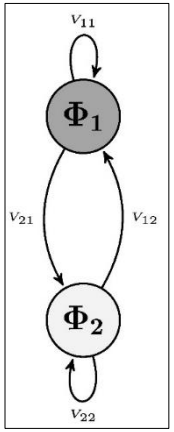


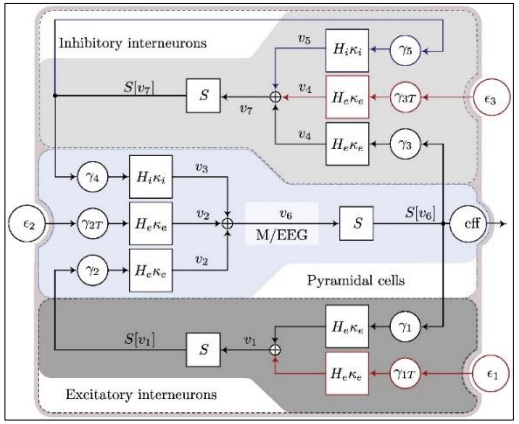
Achard et al. 2006

Modelling neuroimaging data with networks of neural masses









Conclusions

High-resolution structural MRI data used for spatial alignment and identification of where to sample from (e.g. grey matter ribbon)

fMRI: = good spatial, poor temporal resolution

M/EEG = variable spatial; excellent temporal resolution

In practice, generally, we/you are likely to be working with parcellation / ROI time series

-> changes spatial resolution

Macro-connectomics approach: construct whole-brain networks from:

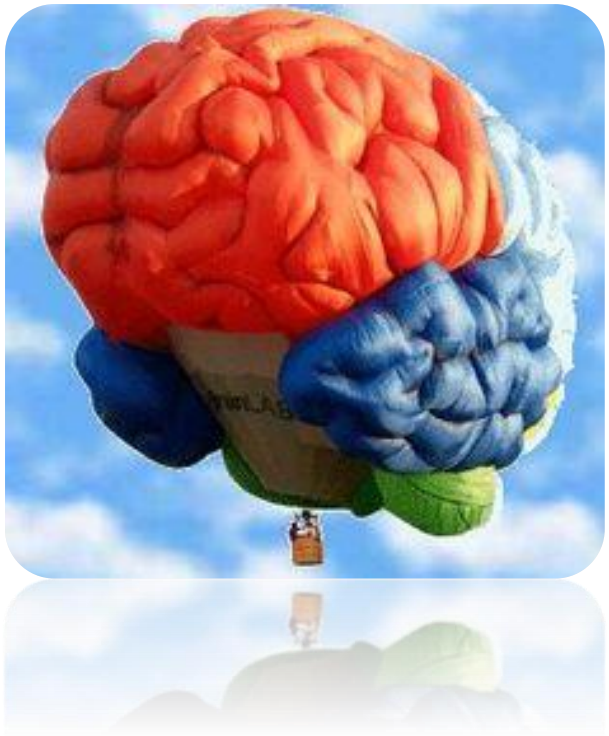
a) synchronization/correlation of ROI time series

-> 'functional connectome'

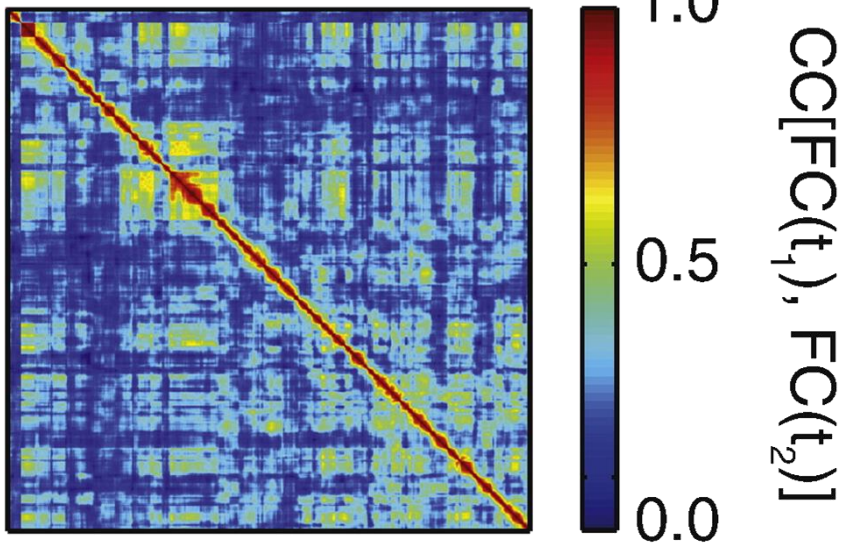
b) strength of anatomical connections

-> 'structural connectome'

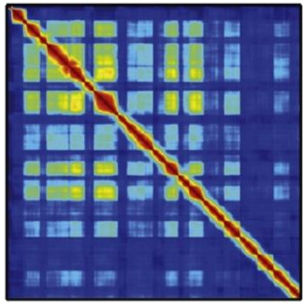
That’s a wrap ☺



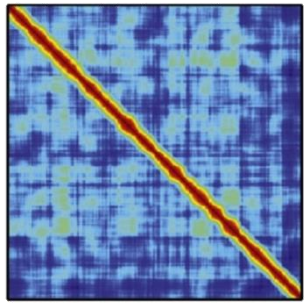
Modelling rsfMRI non-stationary covariance-structure



Empirical rsfMRI FCD



eMFM model



LS model

Hansen et al. 2015